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ARTIFICIAL STIMULATION OF RAIN FORMATION

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Considerable newspaper publicity has been given to reports from the U.S.A. and Australia of rain-making experiments carried out in those countries; "dry ice" pellets or other very cold substances have been sprinkled on clouds which have by this means been induced to release rain or snow. The Moscow press has also reported that workers at the Institute of Physics of Odessa University have caused rain to fall from clouds by dusting them with calcium chloride powder.

The Australian experiments have been described briefly by Kraus and Squires[1*], but the writer has been unable to find any detailed description of the American or Soviet work. It seems likely, however, that the general mechanism stimulated by the Americans and Australians is the same whereas the Russian method relies on the hygroscopic nature of the sprinkled particles and the growth of water drops on them.

Australian experiments.—In the Australian experiments granulated carbon dioxide was dropped, in quantities of a few hundred pounds, on isolated cumulus clouds. In six out of the eight trials, radar observations indicated that rain had formed inside the cloud and on four of these occasions heavy rain was observed visually to reach the ground. One case was doubtful and in one other, in which the cloud extended only 1,000 ft. above freezing level, no change was detected. In all the other experiments the clouds had a vertical extent of more than 10,000 ft. of which at least 4,000 ft. was above freezing level.

One of the most spectacular tests was described in detail. On the afternoon of February 5, 1947, there were 7–8 tenths of cumulus cloud over New South Wales; the base of the clouds was at 11,000 ft., the freezing level at 18,000 ft. and the tops of the clouds uniformly at 23,000 ft. The following is the description of the experiment as given by Kraus and Squires:—

* The list of references is on p. 174.

"At 13.45 hr., 100 lb. of granulated carbon dioxide was dropped into a cloud the top of which was slightly below the general level. After five minutes no visual results were observed. The aircraft flew on, and another test was carried out about twenty miles to the south-west. At 13.56 hr. 150 lb. of 'dry ice' was dropped into a second cloud. The aircraft circled, and in less than five minutes rain echoes from within the cloud were recorded on the aircraft's 10 cm. radar equipment. After the release of a further 150 lb. of 'dry ice', the echoes grew in intensity, and twenty-one minutes after the cloud was first infected an oblique view was obtained which showed heavy rain coming from the base of the cloud. Forty-five minutes later the aircraft descended to 8,000 ft., well below the cloud base, and a pillar of rain covering at least twenty square miles was then seen to reach the ground. Later interrogation of farmers in that vicinity confirmed the occurrence of an isolated rain storm.

"The flight was observed by a 25 cm. radar set at George's Heights in Sydney. Rain echoes appeared on the radar screen in the area of the first drop at 14.03 hr., that is, 18 min. after the release of 'dry ice'. In the second dropping zone, rain echoes were first sighted at 14.12 hr., or 16 min. after the release. It persisted for the rest of the afternoon. No other rain was observed within 100 miles of the aircraft."

The second infected cloud was seen to grow spectacularly and, twenty minutes after seeding, it had a small anvil which later grew to an estimated height of 40,000 ft. The first infected cloud did not grow to such an extent, but these two were the only clouds above the general level of the other tops.

Formation of ice crystals and consequent release of heat.—The exact mechanism of the changes brought about by the granulated carbon dioxide is not certain but is probably the following. Cwilong [2] has found that when clean air is cooled, the water vapour in it will not condense directly into ice crystals until the temperature falls to $-41 \cdot 2°$ C. or less ; with ordinary outdoor air the threshold temperature is $-32 \cdot 2°$ C.

If the processes of condensation in a growing cumulus cloud are the same as in the Cwilong experiment, then we would expect to find super-cooled water particles in the cloud until the $-32 \cdot 2°$ C. level is reached, *i.e.*, roughly 16,000–17,000 ft. above freezing level in the tropics and 14,000–15,000 ft. in this country. Once the cloud has reached this level, ice crystals would be expected, and they, falling through parts of the cloud where the up current was not sufficient to support them, would gradually infect some of the cloud below, so that ice crystals and supercooled water drops would later be found much below the $-32 \cdot 2°$ C. level.

It is not known if this is indeed the case for there are no comprehensive observations as to the first appearance of ice crystals in a growing cumulus cloud. It is known, however, that supercooled water drops are the rule and not the exception, in clouds, for a considerable height above freezing level.

It seems safe to assume, therefore, that the cumulus clouds which were dusted with granulated carbon dioxide were composed of supercooled water drops.

Each granule of "dry ice" would have a temperature of not more than $-65°$C.[3] As the particle falls through the cloud it will cool below $-32 \cdot 2°$C.

by contact, a thin trail of air, supersaturated with respect to ice, or some of the actual supercooled water drops, and will thus leave a trail of ice crystals before it melts. These ice particles will grow at the expense of the supercooled water drops.

The change from the water to the ice state in the cloud will, of course, release heat—the latent heat of fusion—and the denser the original supercooled water cloud, the more heat will be available. This is one reason why the original supercooled water cloud may grow when changed to an ice cloud.

Change in the saturated adiabatic lapse rate of temperature.—Another factor aiding growth of the cloud is the change in the lapse rate of temperature. When saturated air rises, it cools at a slower rate than unsaturated air due to the release of latent heat of condensation. If the temperature is just below freezing, the condensation will most likely be to supercooled water drops and the lapse rate of temperature will be greater than if the condensation were to ice crystals, for in the latter case more latent heat is released. The factors governing the saturated adiabatic lapse rate of temperature are rather complicated, but the writer has recently computed the lapse rates using Brunt's method[4] for temperatures below freezing, for the two cases of condensation to supercooled water and to ice, respectively. The two lapse rates, in conditions usual in this country, are about 0·64°C./100 m. (supercooled water), and 0·55° C./100 m. (ice) at temperatures just below freezing, but the difference between them gradually decreases until it is negligible at heights of 10,000 ft. or more above the freezing level.

It is seen therefore that because of the difference in the two lapse rates of saturated air above the freezing level, the environment may be stable for convective processes where the condensation is to supercooled water, and unstable when the condensation is to ice.

Thus in the supercooled water cloud which has had some of its particles changed to ice, not only will there have been a release of heat to aid further convection but the rate of cooling of the ice parts of the cloud, on further lifting, will be less than for the rest of the cloud and will thus further aid the growth of the cloud.

Order of magnitude of the heat changes in the experiment of February 5. —A few simple calculations may be made to show the order of magnitude of the heating which might be expected from the change from supercooled water to ice particles in the particular case of the experiment described in detail above, and also the difference in the two lapse rates, supercooled water and ice respectively, which would govern the growth of the cloud.

With the aid of a tephigram it is easily seen that the air entering the bottom of the cumulus cloud at saturation at 11,000 ft. will contain approximately 12 gm. of water vapour per kilogramme of dry air. At the top of the cloud at 23,000 ft. the temperature will be about −8° C. and the saturated water-vapour content can only be about 4 gm./Kg. Thus at the top of the cloud there may be as much as 8 gm. of supercooled water per kilogramme of dry air assuming that all the condensed water is carried with the ascending current. This does not allow for any mechanism which may concentrate the condensed water in any one part of the cloud, but this is probably unimportant in a young cloud in which there is as yet no precipitation, for the particles will not be large

enough to have an appreciable velocity through the air and will thus move with the various up and down currents.

There may be, therefore, about 8 gm. of supercooled water per kilogramme of dry air in the top of the cumulus cloud under consideration. If we suppose that 7 gm. of this is quickly changed to ice, the heat released will be 7×75 gm. cal. since the latent heat of fusion of ice at $-8°$ C. is 75 gm. cal./gm.

The heat released is absorbed by :—

7 gm. of ice
1 gm. of supercooled water
4 gm. of water vapour
1 Kg. of dry air.

Thus if $t°$ C. is the resultant rise in temperature of the whole :—

$$7 \times 75 = t\,[(7 \times 0{\cdot}5) + (1 \times 1) + (4 \times 0{\cdot}47) + (10^3 \times 0.24)]$$

since the specific heats of ice, water, water vapour at constant pressure and air at constant pressure are respectively, 0·5, 1·0, 0·47, 0·24.

Hence $t = 2{\cdot}1°$ C.

This would be the local rise in temperature due to the sudden change from water to ice if there were no loss of heat by other means. But of course much of the heat would be transferred by eddy diffusion to other parts of the cloud unaffected by the carbon dioxide granules, and so the rise in temperature of the ice part of the cloud will probably be considerably less than this figure.

In such a sudden change there would also be a small amount of heat released by further condensation from the water vapour direct to ice, since the saturation vapour pressure over ice is less than over supercooled water, but this will be negligible compared with the heat released by the freezing of the free water.

At freezing level, in the cloud, the two lapse rates of temperature will be about 0·53° C./100 m. for condensation to supercooled water and 0·47° C./100 m. for condensation to ice. At the top of the cloud, at 23,000 ft., the rates will be 0·59 and 0·54° C./100 m. respectively. Thus if part of the cloud just above the freezing level, becomes changed to ice particles and moves upwards by convection, when it reaches the top of the cloud, 5,000 ft. above, it will be, taking the mean of the difference of the lapse rates, about 0·8° C. higher in temperature than the surrounding cloud which is still in the form of supercooled water drops even though there was no such difference between water and ice parts, at freezing level. This of course neglects any loss of heat there may have been by conduction or diffusion, in the process.

It is seen, therefore, that the temperature differences caused by the changing of the supercooled water cloud to a part-ice cloud is of the order of 1° C. This is not large but there are many occasions when such a temperature difference would tip the balance in favour of further instability, and probably this was the case in the New South Wales experiments which were made on days when the meteorological conditions were thought to be most favourable.

Formation of rain in the cloud.—The above argument can explain the growth of the cumulus cloud and thus, indirectly, the formation of rain in it, since the deeper the layer of cumulus cloud the more likely the fall of rain from it.

But the report of the experiment says that less than five minutes after the "dry ice" had been dropped, "rain echoes from within the cloud were recorded on the aircraft's 10 cm. radar equipment".

The strength of radar echoes from hydrometeors is governed by three factors:—

(i) the distance of the reflecting drops from the radar instrument,
(ii) the diameter of the reflecting drops,
(iii) the number of reflecting drops per unit volume.

The radar signal, in fact, varies as Nd^6/r^2 where N = number of drops per unit volume, d = diameter of the drops, r = distance between the cloud and the radar set.—Ryde[5].

The rain echoes observed therefore mean that either the diameter of the reflecting drops or their number had increased greatly within 5 minutes of the seeding of the cloud with "dry ice", since presumably the aircraft remained at approximately the same distance from the cloud. The formation of ice crystals of itself would not be expected to make any significant increase in the radar echoes (Ryde, *ibid.*).

But the total volume of the cloud particles is not increased by more than a small fraction by the transition from supercooled water to ice and thus Nd^3 remains almost unchanged in the process. Hence it is possible to say that the diameter of the drops must have increased within the cloud within a few minutes of sprinkling the "dry ice," and to call the echoes "rain echoes" is probably correct.

This is strong confirmation of the theory put forward by Bergeron[6], that moderate or heavy rain falls from clouds containing a mixture of supercooled water drops and ice crystals.

It is not possible to say exactly how the presence of the ice particles aids the growth of the cloud particles to dimensions sufficient for them to fall out as precipitation. Probably the different rates of fall of the ice particles and the supercooled water drops allows the former to grow at the expense of the latter by collision, and the ice particles will also tend to grow by direct condensation because the air, originally saturated with respect to supercooled water, will be supersaturated with respect to ice (Bergeron, *ibid.*). Indeed, once the process has started, it may mean the partial evaporation of the supercooled water-drops into the air, now saturated with respect to ice, and recondensation of this water vapour directly on to the ice particles.

From the data available, it is not known how soon actual rain fell from the bottom of the infected cumulus cloud. After 21 minutes, when the cloud had developed an anvil and had probably reached a sufficient height above freezing level to produce its own ice crystals (i.e. above the $-32{\cdot}2°$ C. level, about 34,000 ft.), rain was seen falling from the cloud, but it may have started quite soon after the "dry ice" was released. It is certain, however, that the continuance of the rain was due to normal shower-cloud processes; once the cloud was induced to grow and could produce its own ice crystals, presumably it could continue to produce rain so long as the heating at the ground continued, which caused the initial convection to bring up water from lower levels.

Turbulence within the cloud.—The rapid changes after the sprinkling of the carbon dioxide give an indication of the remarkable degree of turbulent mixing present within the cloud.

The aircraft presumably could sow the dry ice only over a narrow lane. As explained above, these granules may infect quite a deep layer of the cloud before they melt, but even so, only a comparatively small volume of the cloud can have been reached initially. Yet within eight minutes the cloud had grown considerably. It is inferred, therefore, that within five minutes or so turbulent mixing must have spread the ice crystals formed by the cooling by the carbon dioxide through a large volume of the cloud.

Conditions favourable for the stimulation of clouds.—The foregoing discussion indicates that the conditions suitable for the stimulation of a spectacular growth in a cumulus cloud must lie within rather narrow limits. The environment must be unstable for condensation processes to ice above the original cloud though, of course, stable for condensation to supercooled water, and there must be sufficient free water in the cloud to liberate heat on freezing, sufficient to start off further convection. If the lapse rate of temperature in the environment lies between the two saturated lapse rates, for condensation to supercooled water and to ice respectively, then only a very small impetus is required to make the cloud grow further once ice is induced to form in the cloud. If, however, there is a check in the lapse rate of the environment, above which the air is once more unstable for moist ascent, then the amount of heat which can be liberated by the change from supercooled water to ice is the important factor in deciding whether further growth of the cloud is possible.

Generally speaking, tropical or warm climates will be more favourable for carrying out such experiments than temperate climates. The difference between the two saturated adiabatic lapse rates of temperature for condensation to ice and supercooled water respectively, is slightly greater when the freezing level is high than when it is low, and there is also more water vapour in a hot climate (other than desert) which may be turned into liquid on ascent in a cumulus cloud.

As stated before, the Australian experiments were carried out on days which were specially selected as being considered likely to be favourable. The results of further experiments are awaited with great interest and, in particular, information as to the exact time of the induced rain relative to the growth of the cloud ; whether it actually falls before the cloud can produce its own ice crystals or whether the large growth of the cloud is necessary for the rain formation. It would also be interesting to discover if rain can be induced from a comparatively shallow layer of stratocumulus cloud just above the freezing level and which lies under an inversion or is otherwise prevented from growing upwards.

REFERENCES

1. KRAUS, E. B. and SQUIRES, P. ; Experiments on the stimulation of clouds to produce rain. *Nature, London*, **159**, 1947, p. 489.
2. CWILONG, B. M. ; Sublimation in a Wilson chamber. *Proc. roy. Soc., London*, A, **190**, 1947, p. 137.
3. KAYE, G. W. C. and LABY, T. H. ; Physical and chemical constants and some mathematical functions. London, 9th edn. 1941.
4. BRUNT, D. ; The adiabatic lapse-rate for dry and saturated air. *Quart. J. R. met. Soc., London*, **59**, 1933, p. 351.
5. RYDE, J. W. ; The attenuation and radar echoes produced at centimetre wave-lengths by various meteorological phenomena. "Meteorological factors in radio-wave propagation." London, 1947, p. 169.
6. BERGERON, T. ; On the physics of cloud and precipitation. *P. V. Mét. Un. géod, geophys. int., Paris*, 1935, II, p. 156.

DIURNAL VARIATION OF EVAPORATION FROM NATURAL SURFACES

BY E. J. SUMNER, B.A.

Part II

In Part I a method of determining the diurnal variation of evaporation from a grass surface was indicated, and the final results for Kew set out in diagrammatic form. The values arrived at were shown to be in good agreement with those obtained elsewhere by other means, and this might have been used to justify the method. However, it is felt that some analysis of the factors involved should be given and an attempt made to estimate the probable error.

The limiting factor in the application of the energy method, and the one over which there is still much controversy, is the ratio R associated with the name of I. S. Bowen[1]*. The error in its use is twofold: that inherent in the ratio itself, and that involved in its computation from inadequate climatological data.

Bowen's ratio.—In deriving equation (6) it is assumed, among other things, that eddy diffusion is the only agency at work in the vertical transport of heat and moisture in the atmosphere, and that the steady state exists. Neither of these assumptions is justified; heat is also transported by the exchange of long-wave radiation from one moist layer to another, and equilibrium is seldom attained. It may be remarked in connexion with the latter point that any departure from the steady state would act similarly on the transport of moisture as on the transport of heat, and that, as a result, R would not be subject to very great errors on this account. Also, a rough estimation by the author gave a very small percentage error for both the numerator and the denominator of the ratio due to departure from equilibrium, and it is considered that inaccuracies from this cause may be ignored.

The effect of radiative diffusion is more debatable. Although it can probably be neglected by comparison with eddy diffusion in the free atmosphere, within the semi-boundary layer next to the earth's surface, where the flux of heat and moisture by diffusion is mainly due to molecular processes, it may not be negligible although its absolute value is unknown. Sverdrup[2], using a value for the radiative diffusivity equal to that of the molecular diffusivity of heat, and assuming the coefficient of eddy diffusion to vary linearly with height, calculated that R was too low by about 30 per cent. for a water surface. A similar calculation overland, assuming a power law for the diffusion above the boundary layer, gives more or less the same value. However, experiments by Cummings and Richardson in America indicate a very much smaller error, which suggests that the value for the radiative diffusivity near the earth is much lower than the corresponding value for molecular diffusivity. Even if 30 per cent. is of the right order, since R averages about 0·2 in the present calculations, then $(1 + R)$ is only in error by about 5 per cent. and the evaporation results are 5–6 per cent. too high.

The ratio may, of course, be applied to any surface provided all the items in (6) are known. In the case of a water surface the surface temperature T_0

* The list of references is on p. 178.

may be easily measured and e_G is the saturation vapour pressure at this temperature. For the earth neither e_G nor T_G are measurable owing to technical difficulties, and readings either a little below (more usually in the case of temperature) or a little above the surface are the ones normally taken. The following discussion is concerned with the way in which various difficulties due to inadequate information were met.

Surface temperature.—At Kew, for 1927, temperatures at 10 cm. and 20 cm. below turf were available, and these were extrapolated to the surface assuming homogeneous soil conditions. The phase of this resultant temperature variation, which reached a maximum at 1515 was very much in doubt, although its amplitude was considered to be fairly accurate. Wright[3], from whose paper the data were taken, had pointed out that the observed changes of phase with depth were not consistent with the normal heat conductivity equations, and for this, and other reasons given below, a phase change of one and a half hours ($22\frac{1}{2}°$) was made. T_G at a particular time was calculated using this hypothetical temperature curve, and e_G was taken as the saturation vapour pressure at this temperature. In order to get some idea of the error involved using these values we must consider the relationship between them and the temperature and humidity in the grass a few centimetres above the ground, as the following considerations will show.

The subject is one of great complexity, and one on which much observational work remains to be done. However, it is known that the actual temperature of the grass may differ considerably from the air temperature within it, being generally higher in the day-time, and lower at night near the top whereas lower down this state of affairs may be reversed although the magnitude of the difference is considerably less. Also, the distribution of air temperature within the grass is influenced by its depth, type, luxuriance of growth, and whether the leaves are vertical or not. Early in the year when the grass is short there is probably little modification of the temperature profile from what one would expect with a uniform surface, but later when the grass has grown the temperature at the surface is less during the day than higher up and more at night. In other words, the "effective" surface of the earth is

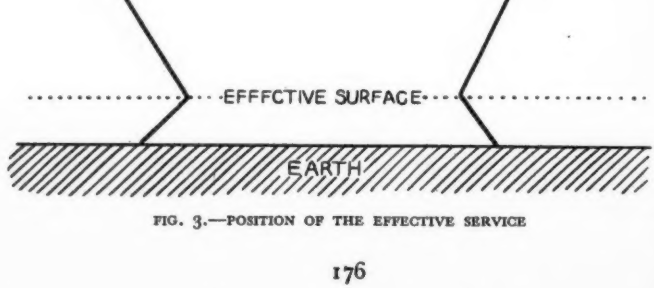


FIG. 3.—POSITION OF THE EFFECTIVE SERVICE

FIG. 1.—VIGOROUS UP-CURRENT IN A CUMULUS CLOUD

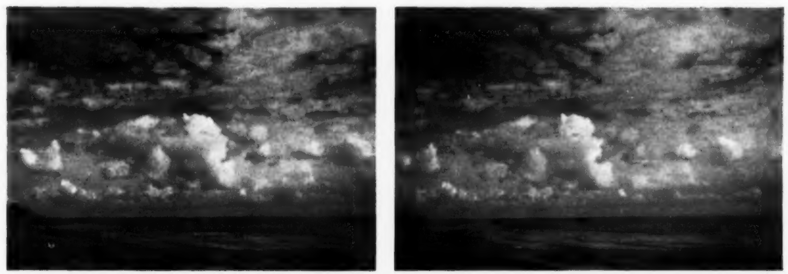


FIG. 2.—ALTOCUMULUS AND CUMULUS SHOWING UNIFORM CLOUDBASE OVER THE SEA

[*To face p.* 176

To face p. 177]

HYPOSTEREOGRAMS

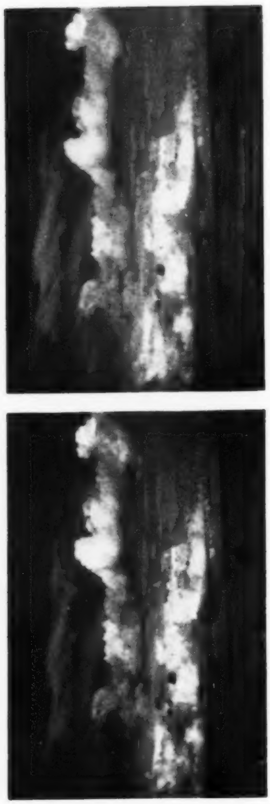


FIG. 3. DISTANT STORM

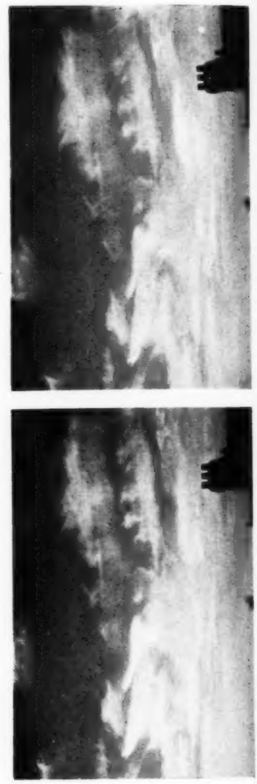


FIG. 4. CIRRUS

raised, being somewhere between the surface and the top of the grass. Fig. 3 illustrates this ; it is not intended to convey the magnitude of the effect, nor is the effective surface necessarily the same by day as by night.

Strictly speaking, it is the temperature and vapour pressure at this "effective" surface which are required in evaluating Bowen's ratio. Curves given by Geiger[4] for a grainfield suggest a maximum difference between the surface temperature and the effective temperature of 1° C. or even less for vegetation over one metre high in summer. It is probable that for turf an error of 1–2° C. is the maximum at all times. Temperature differences of this order make the computed evaporation about 5–10 per cent. too high in the day-time, but at night the percentage error may be great since $e_G - e_A$ in the denominator of R becomes very small making the numerical value of the ratio vary enormously depending on what effective temperatures are used. For this reason, the magnitude of the rate of dew deposition is very much in doubt, especially in spring and autumn when it is probably less than indicated.

The exact time at which the effective surface temperature reaches its maximum is not known, but observations made by Best[5] at 2·5 cm. above closely-cropped grass for clear days in March (1931–3) gave a time of 1400 and an extrapolated surface maximum was found to be at 1330.

Taking into account all the above points it seems that the diurnal curve got by extrapolating to the soil surface and altering the phase by one hour and a half (so as to give a maximum between 1330 and 1400) gives a good enough approximation to the effective temperature, especially as the difference $T_G - T_A$ is then found to have a maximum nearer midday in agreement with Best's observations.

Surface vapour pressure.—Readings of vapour pressure near to the earth's surface are few and far between. In spite of the large evaporation of plants during the day-time and the relatively high leaf temperature, absolute saturation is seldom obtained in the adjacent air. However, Geiger quotes observations by O. Stocker which showed a very steep humidity gradient above a cover of vegetation. For example, an observation taken in a meadow near Freiburg on a hot almost windless day (when the air temperature was as high as 29° C.), at 2 cm. above the ground, among grass, gave the humidity as 96 per cent., whereas at 100 cm. in the free air it was only 57 per cent. Other observations show equally high humidities among vegetation.

The saturation vapour pressure at the surface temperature (not the effective temperature) is evidently representative of that at the effective surface to a high degree of accuracy except possibly during periods of drought in summer and autumn.

Other terms.—Most of the complications in the previous section were due to the presence of a covering of vegetation having different thermal characteristics to the soil. The evaluation of H, the heat storage, presented the same difficulties, and a similar device was employed to surmount them.

In the experiments conducted by Wright it was found that grass interfered with the normal process of heat conduction and it was suggested by comparison with observations taken below bare soil that the time taken to transmit heat through the grass was about an hour and a half. Thus the heat storage deduced from soil temperatures must only be used in conjunction with values

of the other elements for an hour and a half previously. Accordingly H was calculated from equation (3) using the same hypothetical surface temperature as before.

The heat stored in the grass itself was neglected and no account was taken of the lack of homogeneity of the soil. The effect of an increase in H on the total evaporation is very small although it alters the profile of the diurnal curve somewhat, making both the evaporation and the deposition slightly less.

The maximum errors arising from all the causes so far discussed are cumulative, but together they represent only 10–15 per cent. of the total evaporation. An added source of error, and one which can easily equal the previous ones, arises in the determination of the insolation at places where continuous pyrheliometer readings are not available, which is more often the case. At Kew pyrheliometer readings were taken only once a day within half an hour on either side of noon when the sky was clear, and this provided a rough check on the theoretical values used. It is not proposed to enter into the intricacies of the computation here; details are to be found elsewhere—see Brunt[6], Richardson[7], Ångström[8].

Another error is in the reflectivity of a grass surface, which in the present work was taken as 20 per cent. of the incoming short-wave radiation at all seasons. This figure is probably too high, but, since it reduces the evaporation whereas the other errors tended to increase it, some compensation is provided.

Conclusion.—There seems to be a wide-spread misconception among meteorologists that the amount of water lost by evaporation over land is negligible by comparison with that from the sea, and some authors in recent times have ignored it completely. Having regard to the diversity of types of grasses, cultivated crops, etc., and the fact that only a single year's values have been computed, it is impossible to generalise the results found for Kew, but it is manifest that land surfaces covered with living vegetation lose a considerable amount of evaporated water, especially during the growing season. For example, the total evaporation at Kew for 1927 was about 41 cm. (about half the rainfall) which is equivalent to just over 1·1 mm./day averaged over the whole year. This may be compared with 1·87 mm./day obtained theoretically by Frost[9] for the Atlantic Ocean in these latitudes, and Jacobs' average figures of 2·2 mm./day for the Atlantic at 50°N.[10]

The energy method is tentative in application, and the accuracy of the results is impaired by lack of observational data. More investigation is required before one can predict the diurnal variation of evaporation with any degree of confidence, although the favourable comparison between existing results and those found here encourage the author to think that sufficiently accurate values can already be found for practical purposes.

REFERENCES

1. BOWEN, I. S.; The ratio of heat losses by conduction and evaporation from any water surface. *Phys. Rev., Minneapolis, Minn.*, **27**, 1926, p. 779.
2. SVERDRUP, H. U.; On the ratio between heat conducted from the sea surface and the heat used for evaporation. *Ann. N.Y. Acad. Sci., New York*, **44**, 1943, p. 81.
3. WRIGHT, H. L.; The variation of soil temperature below turf. *Mem. R. met. Soc., London*, **4**, 1931, No. 31.
4. GEIGER, R.; Das Klima der Bodennahen Luftschicht, *Wissenschaft, Braunschweig*, **78**, 1927.
5. BEST, A. C.; Transfer of heat and momentum in the lowest layers of the atmosphere. *Geophys. Mem., London*, **7**, 1935, No. 65.

6. BRUNT, D.; Physical and dynamical meteorology, Cambridge, 1939.
7. RICHARDSON, B.; Evaporation as a function of insolation. *Trans. Amer. Soc. civ. Engineers, New York*, **95**, 1931, No. 1,782, p. 996.
8. ÅNGSTRÖM, A.; On radiation and climate, *Geogr. Ann., Stockholm*, 1925, p. 122.
9. FROST, R.; Turbulence and diffusion in the lower atmosphere. *Proc. roy. Soc. London*, A, **186**, 1946, p. 20.
10. JACOBS, W. C.; Sources of atmospheric heat over the North Pacific and North Atlantic Oceans. *Ann. N.Y. Acad. Sci., New York*, **44**, 1943, p. 19.

THUNDERSTORM OF JUNE 27, 1947

This thunderstorm attracted particular attention in the London area owing to the darkness and severe squall which accompanied it. Mr. E. Gold wrote the following account of the storm in London :—

"An outstanding feature of the storm here was that underneath the very black cloud which was moving eastwards there was practically no rain and no wind. The rain could be seen to the south-west against what appeared to be a rather bright sky but did not begin at Victory House until the western edge of the dark cloud was practically overhead. Then the rain began to fall in torrents and the wind rapidly increased. The dark cloud was really very black and it was impossible to read without artificial light, even in my room on the 7th floor. The intensity of the rain, no doubt combined with splashing from the roofs, reduced visibility so much that it was practically impossible to see across Kingsway at roof level, i.e. visibility was less than about 30 yards."

At Kingsway the squall gave a maximum gust of SSW. 64 m.p.h. at 1120 G.M.T., with a sharp rise of pressure of 2 mb. At Kew Observatory the peak of the squall was 230° 53 m.p.h. at 1130. Mr. G. Seligman also noted the squall at Wimbledon. Rainfall exceeded 1 in. over most of London and amounted to 1·66 in. at Greenwich. Its duration at Kingsway was 70 min. At South Farnborough the extreme was only SSW. 19 m.p.h. at 1050 G.M.T., and there was no sharp rise of pressure. At Dunstable the extreme was SSW. 20 m.p.h. and pressure rose sharply 4 mb., with a double peak, the second one at a secondary squall. The squall can be attributed to cooling by precipitation, probably including the melting of very heavy hail, with the stones too small to reach the ground. Wet-bulb temperature fell with the squall at Dunstable to 61° F., some degrees less than the wet-bulb potential temperature at any height. The freezing level was at 12,000 ft., where there was a very strong southerly wind. The worst squalls accompany strong upper winds, but the dynamical problem is complex. The descent of cold air must always involve some spreading out at a low level.

The cloud structure at Dunstable (as in London) showed some evidence of an upper cold front. Just before the rain black mammillated clouds were moving from west-south-west at an estimated height of fully 7,000 ft., possibly 8,000 ft., though the storm itself was approaching from the south. The dark cloud had a straight edge to westward but the brighter region soon receded to the north-west horizon as the storm area spread west, probably the result of the northward movement of the widest part of the storm.

The thunderstorm was one of a series which broke out over Spain, south-west France and the Bay of Biscay (shown by atmospherics only in the Bay) on the previous late afternoon and evening, and moved quickly northward in

the upper current. It was a fairly typical high-level storm, but there were some unusual features on the sea-level charts. The main front was off Scilly at 1200 and moving very slowly (see Fig. 1), but further east there was a large horizontal gradient of temperature, associated with exceptional heat on the continent. According to reports in the Press, the maximum temperature of 101° F. at Brussels on the 27th was a record for June. At Kew the minimum of 67° F. on the night of the 26th–27th was the highest on record for June. The temperature at 950 mb. (about 2,000 ft.) at Downham Market rose from 72 to 77° F. between 1800 and midnight and then fell. The southerly current over England (backing SE. in the south) fell off rapidly in the night and was

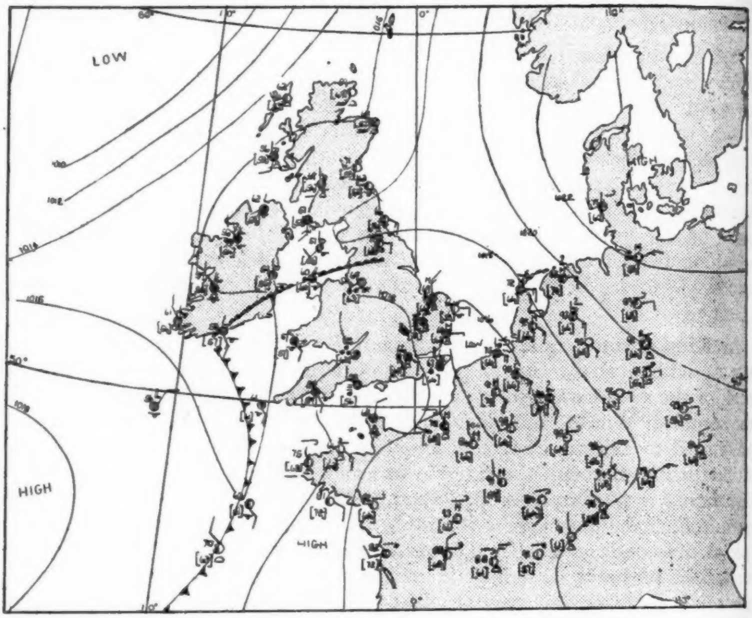


FIG. 1.—SYNOPTIC CHART AT 1200 G.M.T., JUNE 27, 1947
Dew-point temperatures are given in brackets.

replaced by a weak NW. wind over the Midlands, quickly spreading over eastern England. This was confined to a very shallow layer but it was accompanied by an advection of colder air with frontogenetic action near the east coast, though it is difficult to locate a definite front. The upper frontal action observed at London and Dunstable was probably related to the diffuse frontogenesis to eastward lower down.

A wedge of high pressure developed over the Bay of Biscay during the night of the 26th–27th and by 1200 on the 27th there was an elongated anticyclone, as shown on Fig. 1. The 700 mb. contours (Fig. 2) show that it was a very shallow anticyclone. At 1800 there was a shallow cold anticyclone from the Midlands to the English Channel, which moved to the north-east and intensified, developing a central pressure of 1027 mb. off Norway by 0600 on the 29th. The air in which it formed was greatly cooled by precipitation falling

into it from above, and this may have given the trigger action which started the anticyclonic development, though it is impossible to prove this in the present state of our knowledge.

The thunderstorms over Spain and south-west France on the previous evening finally developed into an area of continuous rain with little or no thunder, and this moved rapidly northward over western England and Wales during the morning. The thunderstorms which affected the eastern districts of England developed over north France early on the 27th near the east boundary of a region of widespread rain, which accentuated an already steep horizontal temperature gradient. The storms moved quickly north and one had already

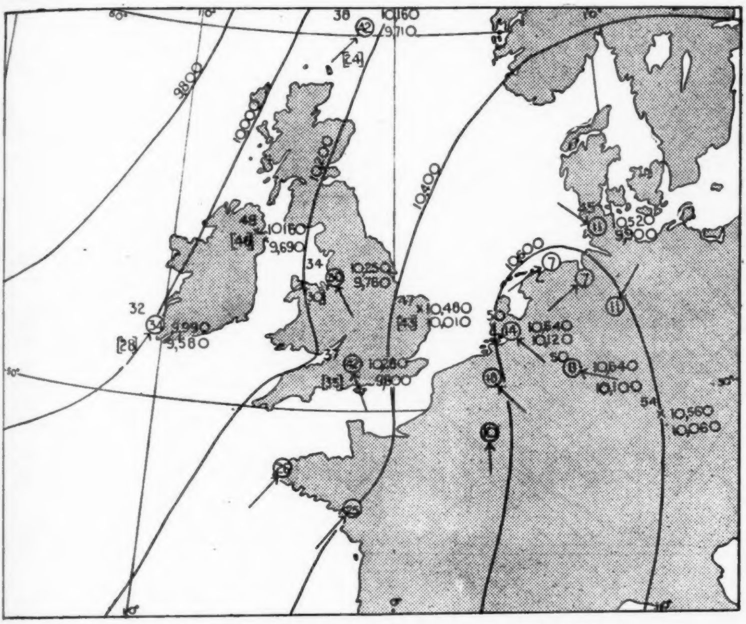


FIG. 2.—UPPER AIR CHART AT 1200 G.M.T., JUNE 27, 1947

Figures on right of stations are (top) heights of 700 mb. surface above sea level and (below) heights above 1000 mb. surface. Figures on left of stations are dry-bulb temperatures and (in brackets) wet-bulb temperatures at 700 mb. Wind velocities are given in knots inside station circles. Heights are given in feet.

reached West Raynham (north Norfolk) by 1000 G.M.T. There were a number of scattered early storms, including a brief one in London 50 min. before the main one. The main storm was much larger than the earlier ones and its front boundary was orientated north-west to south-east with a length of about 100 miles, though the length of the most intense part of it was less. Judging from the duration of rain in relation to the speed of movement, the width of the belt (in direction south-west to north-east) was 40 miles in the London-Dunstable region, but only some 20 miles at South Farnborough. Its vertical extent was very great, the top probably being at least up to the tropopause at 41,000 ft. Radar echoes up to 40,000 ft. were observed by the Royal Aircraft Establishment, South Farnborough, when the storm was near

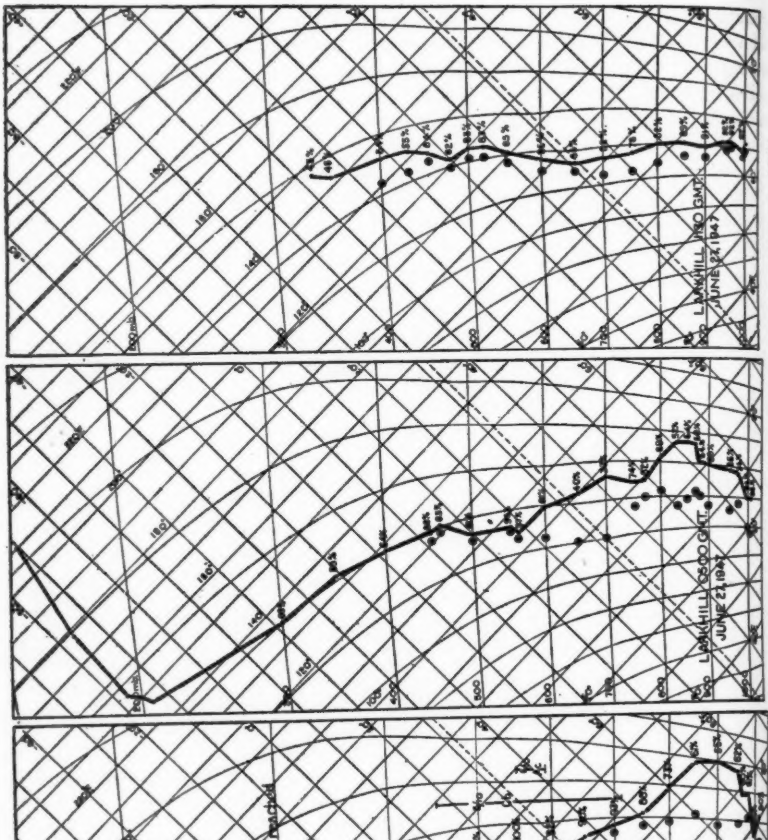


FIG. 3.—TEPHIGRAMS OF UPPER AIR ASCENTS AT COLTISHALL AND LARKHILL ON JUNE 27, 1947

the south coast at 1000 G.M.T., and to just above 40,000 ft. from East Hill, Dunstable, when the storm was in the Cambridge-Mildenhall area. The storm moved north at a speed of just over 40 knots, derived both from the autographic records and from the successive sets of observations of atmospherics. This is a lower speed than might have been expected from the Larkhill winds at medium levels at 1200 (see Table I) but these were probably in excess of the wind in the storm area. The geostrophic wind at 700 and 500 mb. cannot be measured with accuracy owing to the eastward decrease of gradient, but it is consistent with a mean wind between the two levels little in excess of 40 knots.

TABLE I—UPPER WINDS AT LARKHILL

Pressure	0600 G.M.T.		1200 G.M.T.		1800 G.M.T.	
mb.	°true	kt.	°true	kt.	°true	kt.
950	220	10	190	9	260	6
900	220	10	190	7	260	8
850	220	15	200	12	260	10
800	220	22	200	21	250	12
750	210	23	190	26	250	18
700	200	30	170	42	250	22
650	200	32	150	60	240	29
600	180	40	170	57	240	33
550	180	42	190	57	230	38
500	190	43	180	52	230	44
450	190	46	170	63	230	49
400	190	44	—	—	240	46
					210	46

There were no wind observations at Downham Market.

The storm was still active over Yorkshire at 1500 G.M.T. but after it went over the North Sea it rapidly lost intensity and only a few atmospherics were recorded. Since the storm was a high-level one the decrease in intensity after leaving the land must have been largely accidental. There was some decaying medium cloud behind the storm, but the evening was brilliantly fine. The fine weather moved northward from France, and since the temperature gradient was east-west it cannot be explained in frontal terms.

The tephigrams (Fig. 3) show marked latent instability aloft. The cloud observation at Coltishall only refers to the outlying clouds, and the tops of even the earlier storms were probably much higher. The base of the main cumulonimbus masses was probably not below 7,000 ft. The most interesting feature is the change at Larkhill between 0600 and 1200. The wind was light up to 5,000 ft. and most of the cooling must have been due to the rain. The wet-bulb temperature had only fallen slightly at certain levels, while at some levels it had risen. By 1800 dry-bulb and wet-bulb temperatures had risen slightly up to 600 mb. (14,000 ft.). Higher up temperature rose slightly between 0600 and 1200 and fell slightly by 1800, with a temporary veer of wind. The trough at 700 mb. (Fig. 2) was over a tongue of cold air which did not extend much higher up, and was due partly to precipitation.

C. K. M. DOUGLAS

At Croydon, a violent squall accompanied by a thunderstorm and heavy rain occurred between 1100 and 1115 G.M.T. At 1110 the barometer rose 7 mb. and then fell 5 mb. Temperature dropped 12° F., approximately 1 in. of rain fell in about 15 minutes. The wind which had been light suddenly increased to gale force and gusted up to 73 m.p.h. and, a few minutes before the squall, backed from roughly NW. to S. and then veered rather more

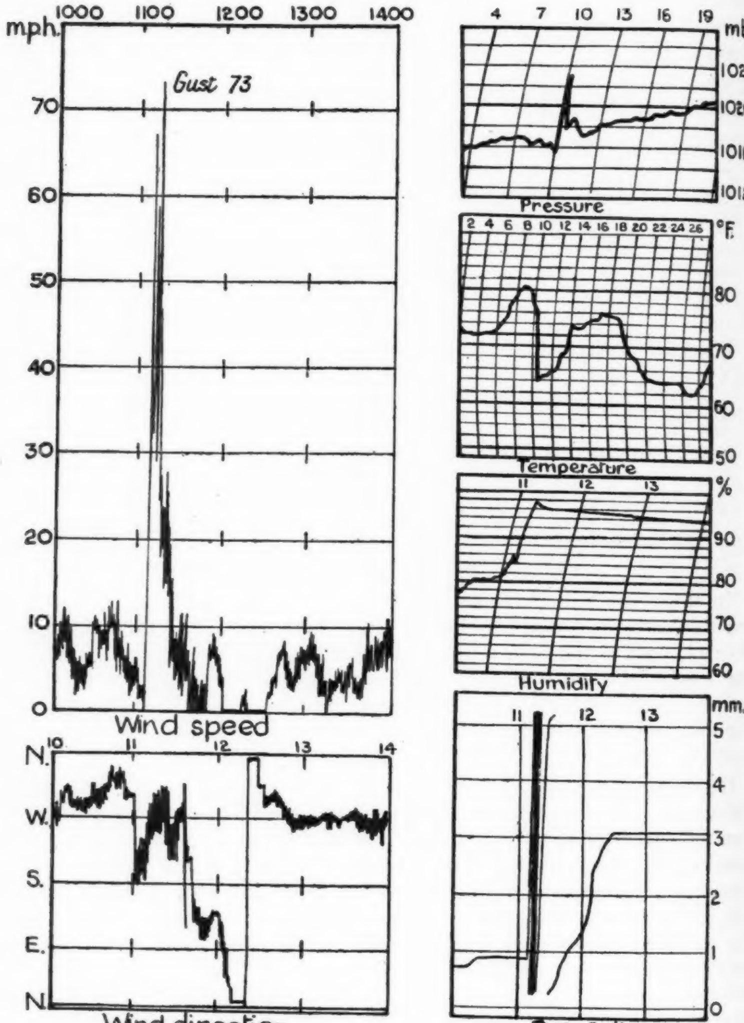


FIG. 4.—AUTOGRAPHIC RECORDS AT CROYDON, JUNE 27, 1947

The barograph is one hour slow ; the thermograph is three-quarters of an hour slow ; the wind-direction graph is about ten minutes slow.

EFFECT OF WATERSPOUT IN ORKNEY, AUGUST 5, 1945
View taken from disturbed area looking south-south-west showing large chunks of earth uprooted by the waterspout. (see p. 187).

General view looking north-east showing part of disturbed area in the foreground (taken at a distance of 150 yards on August 9.

View taken from the middle of the disturbed area looking south-east down the valley towards Isbister Bay. The burn into which the water drained can be seen in the middle distance.

EFFECT OF WATERSPOUT IN ORKNEY, AUGUST 5, 1945

(see p. 187)

gradually to NW. again. Tracings of the autographic records are shown in Fig. 4.

Mr. H. V. Sims, the meteorological observer at the Grammar School, Earl's Colne, Colchester, writes :—

"On Friday, June 27th, after an ordinary thunderstorm at midday, we were visited by a veritable tornado. Towards 2 p.m. the sky became inky black; thunder and lightning approached again; the wind changed in a few minutes from SE. to SW. and increased to gale. Rain started and then suddenly increased to torrential with visibility down to about 20 yards. At the same time we saw a whirlwind cross the playground and, in its midst, waltzed a heavy door wrenched from the gymnasium. This was finally smashed to pieces (the door). Most of my beehives were overturned and the screen, in spite of repairs after the recent accident (and a ½-cwt. block of concrete), was thrown five yards leaving me with only the shade min. intact.

"In the village, the gale brought down many trees, chimneys and roofs. Some lead roofing on the school was stripped right back and smashed the tile roof on which it landed. Part of the roof of the machine shop at the Atlas Works, Earl's Colne, was blown in, luckily without personal damage. I estimate that approximately 0·85 in. rain fell in about thirty minutes. Floods, of course, were widespread for the next hour or two. Unfortunately, I was too excited to observe the behaviour of the barometer."

L. F. LEWIS

METEOROLOGICAL RESEARCH COMMITTEE

The meeting of the Meteorological Research Committee held on July 17 was an unusually interesting one. In the first place, it witnessed the strengthening of the Committee by the addition of two new members, Professor P. A. Sheppard and Professor O. G. Sutton. The Committee already includes many of the most eminent meteorologists in the country, and the Air Ministry may well regard itself as fortunate in acquiring two additional members of such distinction.

In the course of the meeting, the Committee decided to form three sub-committees, each of which will be responsible for one of the three sections into which the research programme is divided, viz. Instruments, Forecasting, and Physical and Dynamical Problems. The primary reason for establishing these sub-committees is to permit of more detailed discussion of highly specialised matters than is possible in full Committee. It is also intended to give an opportunity to those actually engaged on the problems to participate in the discussion of their work by the sub-committees. The view was also widely supported that the sub-committees should hold their meetings at places where investigations are in progress.

Among the other subjects discussed at the meeting on July 17 was the artificial production of rain described by Kraus and Squires in their article in *Nature* of April 12, 1947. Many readers will remember Dr. Kraus as the able and energetic young meteorologist who took a prominent part in developing the Meteorological Reconnaissance Flights during the war, and subsequently served as the Senior Meteorological Officer at the Photographic Reconnaissance Unit at Benson. The physical explanation of the experiments performed by Kraus and Squires does not present any great difficulty, but some members of the Committee expressed surprise that such a

limited amount of solid CO_2 should produce rain over an area of many square miles, and that the effect should take place so rapidly. Further information on these points is being sought, both from Dr. Kraus and also from Professor Langmuir, who has been responsible for some similar experiments in America.

ROYAL METEOROLOGICAL SOCIETY

The Summer Meeting of the Society took place on Saturday July 5, when a visit was made to Portsmouth Dockyard.

About one hundred Fellows and their guests left Waterloo Station at 10.45 a.m. and, arriving at Portsmouth around 12.30 p.m., split into two parties, one led by W/Cdr. Poulter and the other by Cdr. Burgess. After having lunched the parties proceeded separately to the Dockyard, one to visit the aircraft carrier, H.M.S. *Illustrious* and the other Nelson's flagship H.M.S. *Victory*.

On boarding the *Illustrious* the party was welcomed by the senior officer on duty and quickly split into parties of ten for a rapid tour of the ship. In an incredibly short space of time we walked the flight-deck, crowded into the tiny meteorological office, visited the bridge and descended by the aircraft lift to the spacious hangers below. Already, so early in the afternoon, we were glad of that lift—'tween-deck ladders on board naval vessels are obviously not constructed for the comfort or convenience of landsmen, especially when they happen to be in a hurry. We would have liked more time to see more but it was enough to enable us to appreciate the vast and detailed organization necessary for the efficient running of a great ship.

Having come to the end of our allotted time on the *Illustrious* we changed places with the other party and proceeded to the *Victory*. This again was of necessity a short visit but an extraordinarily interesting one coming directly after our tour of a modern aircraft carrier.

At about 3 p.m. the two parties joined up and walked through the dockyard to the radar-training ship H.M.S. *Boxer*, where we were received with traditional naval courtesy by the Captain and officers. As soon a the whole party had gathered in the lecture room, the Captain of the ship, Cdr. C. J. Wynne Edwards, D.S.C., R.N., gave us a short talk about the *Boxer*. Built originally as an L.S.T. (Landing Ship, Tank) she had been converted into a Fighter-Direction Ship for use in the Pacific. When the war came to an end she underwent considerable alteration and was fitted out as a training ship for officers and ratings in the use of radar, her present function. Cdr. Wynne Edwards was followed by the Navigation Officer, Lt. W. G. Wright, Royal Australian Navy, who briefly explained the main uses of radar at sea. To implement his talk and make things clearer to the struggling lay minds of some of us, an interesting film, explaining the elementary principles of radar, was shown. Lt. P. G. Satow, D.S.C., R.N., then described the uses of radar in meteorology. At the moment its main use is in following the corner reflectors carried aloft by balloons and so making possible the determination of the speed and direction of the upper winds. Equipment used for this purpose has been fitted in the ocean weather ships now starting operations in the North Atlantic. On trial, as shore equipment, this instrument gave ranges up to 45 miles at a vertical height of 58,000 ft., but its maximum range, when used under Atlantic conditions, is more likely to be of the order of 20 miles. In addition to the determination of upper winds, radar can be of invaluable use to the meteoro-

logist in the detection of rain-bearing clouds. Shower and thunder clouds can be located at a considerable distance and their tracks plotted. The great advantage of being able to do this is obvious. With the full employment of radar in this way the present danger of an aircraft being caught in a suddenly appearing and violent convective storm would be obviated. Great use was made of this during the recent war. Naval forces frequently took cover beneath large rain clouds only steaming out into clear weather long enough to enable the carriers to fly off or fly on their aircraft. It was a pity that time would not allow the speakers to tell us more about this fascinating subject.

A tour of the ship followed, each small party being shown round by one of the ship's officers. One is at a loss how to describe the inner workings of such a ship for it is literally crammed full of the latest types of radar equipment; plan position indicators, direction finders for surface vessels, height finders for aircraft, short-range navigation sets which enable ships to find their buoys at night or in fog, homing beacons for aircraft in thick weather and innumerable other instruments which left us wondering—what next? A somewhat bewildered and very tired—even more and steeper ladders here—party of meteorologists finally found its way to the officers' wardroom where a very welcome tea was being served.

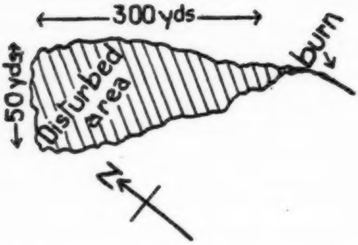
Before leaving the *Boxer* Mr. Shipley thanked Cdr. Wynne Edwards for allowing us the privilege of such a wonderfully interesting afternoon on his ship and voiced the party's appreciation of the kindness shown by his officers in giving up their shore leave for our benefit and instruction.

It was a most successful meeting, greatly appreciated by all those lucky enough to be present. We only regretted the speed with which it was conducted. No doubt there were good and sufficient reasons for that. We were rather left feeling however that we had seen and learned a lot but had also missed much which would have proved equally interesting and instructive.

LETTERS TO THE EDITOR

Waterspout in Orkney

On Sunday, August 5, a waterspout was observed in Orkney between about 0930 and 0955 clock time. It was first noticed crossing the Bay of Isbister (about 5 miles north-west of Kirkwall) travelling in a north-westerly direction, the funnel pendant from a large cumulus cloud but not reaching the ground. In its travel north-west, the waterspout encountered the slopes of Milldoe Hill (735 ft.) at a point near the top where a small burn has its source. The burn runs down to the south-east and drains into the Bay of Isbister. Near the top of the hill, in its travel up the burn, the lower end of the waterspout appears to have reached the ground, because there was considerable disturbance of the surface over an area of length 300 yds., max. width near the top 50 yds. as in sketch below. The edges of the disturbed area were quite sharp though not straight. The top soil which is covered with heather and coarse grass had been torn apart to a depth of 3 or 4 ft., broken up and thrown about into large chunks each weighing several hundredweight. A considerable amount of water had evidently fallen from the spout at this point and flowed down the hill as several large pieces of earth had been washed to the side of the area. Facing p. 184 and p. 185 are photographs of this disturbed area taken on August 9, 1945. The top of the hill was undisturbed, and the waterspout was observed to travel across country in a north-westerly direction



for another 5 miles before finally disappearing at 0955. There were no other traces on the ground except at the place described above.

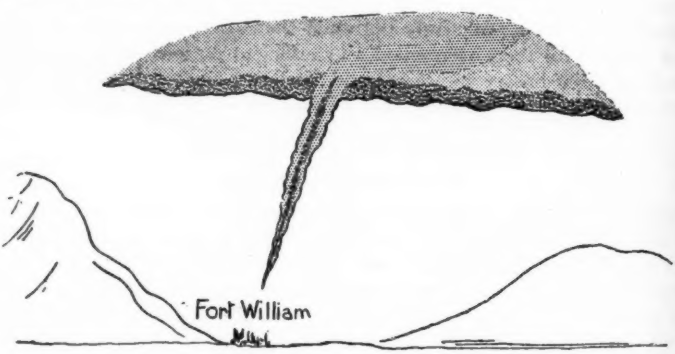
I saw the waterspout myself from Twatt aerodrome from 0950–0955, bearing east and it appeared to be passing behind Greenay Hill (2½ miles away). It disappeared shortly afterwards.

C. S. PORTER

R.N. Air Station, Twatt, Orkney, August 13, 1945.

Waterspout at Fort William

I was at Gairlochy, on the Caledonian Canal, about 2 p.m. on Sunday, August 5, and had been watching the sky over Fort William, where a large black cloud coming from the south-west seemed to indicate a change of weather. Very suddenly a long pointed finger appeared to shoot down from the black cloud in the manner in which I believe a waterspout begins, but the extremity did not reach ground level. It appeared to hang stationary for about 3 minutes although it may have been travelling in my line of sight. Small pieces of cloud seemed to be swirling down one side and up the other. The sketch below gives a rough idea of its appearance.



The weather before the change had been fine with light W. or NW. wind, good visibility, and about 4 or 5 tenths cumulus with well defined outline, and clear blue sky between, except away to the south, where the blue sky became obscured by a fine veil as if of fine cirrus. The extreme tip of Ben Nevis was hidden in cloud. Shortly after the above-mentioned effect, rain started, and continued for an hour or two, with a shift of wind to the NE., moderate and cooler, especially the following day.

GILBERT O. KOLLEN

5 *Hillview Terr., Edinburgh*, 4. *August* 14, 1945.

[On August 4, 1945, a shallow depression was centred to the north of the Faroes and a cold front crossed Scotland during the day. By the morning of the 5th another centre of low pressure was developing to the east of Scotland on this front which was almost stationary over the North Sea. Ed. *M.M.*]

NOTES AND NEWS

A simple method of making hypostereograms of clouds with a single camera

Binocular vision ceases to produce any perceptible appearance of solidity at distances greater than about two to three hundreds yards. A normal landscape viewed from the air appears, for example, dead flat, the only clues to the height of objects on the ground being afforded by cast shadows. In such cases the retinal images obtained in each eye differ only by amounts that are too small to be resolved. This is also the case with views of clouds, the shapes and positions of which can only be appreciated through similar indirect effects of cast shadows, absorption of light in the atmosphere and perspective.

The stereoscopic camera enables this normal maximum distance of stereoscopic vision to be multiplied many times photographically by the simple expedient of increasing the distance between the lenses. In certain cases two exposures with a single camera, taken the requisite distance apart, may be used. This is the case with objects that remain fixed throughout the time required to make the exposures and to transfer the camera from one position to the other. The use of the stereoscope in this way for the interpretation of aerial photographs will be familiar to most.

Suitable stereoscopic pairs may often be obtained with cloud photographs in an extremely simple manner. The drift of the clouds with the wind is frequently sufficient to provide the requisite displacement between two photographs taken within a few seconds of each other from the same position. The interval between the two exposures may be made sufficiently short so that the clouds do not change appreciably. As it is desirable for the relative displacement between the two pictures to be horizontal (otherwise the photographs would have to be mounted with inclined horizons for viewing) it is necessary for the camera to be pointed in a direction at right angles to the wind. For example, with a N. wind the clouds to be photographed should lie either to the east or west of the observer. The exposures are made in the ordinary way using a panchromatic film and a deep yellow filter, and the interval between the two exposures necessary to produce a good effect of depth under ordinary conditions is about 5 seconds. This is roughly the time required to wind on the film and make the exposures. With low cloud the interval should be shorter and with high cloud longer but its exact length is not in the least critical.

The accompanying plates (facing p. 176 and p. 177) show four pairs of photographs taken in this way for viewing in an ordinary stereoscope. The first pair (Fig. 1) shows a vigorous up current rising vertically from a layer of cumulus cloud. Fig. 2 is of interest as showing the level cloud base over the sea. The cumulus clouds, though of varying sizes, all have their bases on the same level. Fig. 3 is of a distant storm the summits of which are seen to be partially masked by the nearer and lower clouds. Fig. 4 is of cirrus. The depth is not portrayed very markedly—a longer interval between the exposures would have been desirable—but a curtain of falling particles may be observed under many suggesting an explanation of the normal " spun out " appearance of this type of cloud.

In viewing the photographs the landscape should be neglected. In this there is no displacement so that it appears at the back of everything. Figures are a

nuisance as they often appear in totally different positions in the two photographs. In photographing clouds, however, it is necessary to seize one's opportunity and it is not always easy to exclude the unwanted figure at the precise moment and in the required direction !

R. A. R. TRICKER

WEATHER OF JUNE, 1947

Pressure was low over the north-east Atlantic, high from the Azores to Spain and relatively high in a wedge across France and central Europe to the Black Sea ; it was also relatively high in the Arctic region from north-east Greenland to Spitsbergen. Mean pressure for the month ranged from 1007·2 mb. on the Atlantic (50° N. 30° W.) to 1021·2 mb. at Horta in the Azores. Differences from the average showed a large area on the Atlantic of more than 5 mb. below average and an area near Spitsbergen of rather more than 4 mb. above average.

Over the British Isles the greater part of June was characterised by depressions or troughs of low pressure travelling north or north-east over the country. Southerly or south-westerly winds predominated, with excessive rainfall on the whole, though less than the average occurred over a large part of the Midlands. Thunderstorms occurred rather frequently and some were severe. It was sunnier than usual in east and south-east England but dull in the west and north of the British Isles. The opening days were exceptionally hot.

Mean temperature exceeded the average, the excess being greatest in the eastern half of England. The first three days were exceptionally hot over much of England ; on the 3rd, temperature reached or exceeded 90° F. at a large number of stations in the eastern half of the country ; at some stations in this area, for example at Kew Observatory with its long meteorological record, it was the hottest June day on record. The month was wet on the whole; more than twice the average rainfall was received over a small area in the Fens, in the Scilly Isles, around Garvagh, County Londonderry, in a small area in Perthshire and at Kelso. The thunderstorms on the 27th were severe in the south-eastern counties (see p. 179).

Generally speaking the month was dull ; in east and south-east England, however, it was somewhat sunnier than usual. In Scotland the deficiency was marked ; at Leuchars, it was the dullest June since observations were started in 1922 and at Dundee the total sunshine was the lowest in June for at least 30 years.

The general character of the weather is shown by the following table :—

	Air Temperature			Rainfall		Sunshine	
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days' diff. from average	Percentage of average	Percentage of possible duration
	°F.	°F.	°F.	%		%	%
England and Wales	94	35	+ 2·6	112	+ 1	91	37
Scotland	80	32	+ 1·3	147	+ 5	69	23
Northern Ireland	75	37	+ 1·7	159	+ 4	82	28

RAINFALL OF JUNE, 1947

Great Britain and Northern Ireland

Co.	Station	In.	% of Av.	Co.	Station	In.	% of Av.
London	Camden Square	2·74	136	*Glam.*	Cardiff, Penylan	2·62	104
Kent	Folkestone Cherry Gdns.	3·00	151	*Pemb.*	St. Ann's Head	2·86	137
,,	Edenbridge, Falconhurst	2·77	126	*Card.*	Aberystwyth	1·97	80
Sussex	Compton, Compton Ho.	2·45	98	*Radnor*	Bir. W.W., Tyrmynydd	2·84	87
,,	Worthing, Beach Ho. Pk.	2·42	138	*Mont.*	Lake Vyrnwy	4·11	126
Hants	Ventnor, Roy. Nat. Hos.	1·88	103	*Mer.*	Blaenau Festiniog	5·32	82
,,	Fordingbridge, Oaklands	1·75	95	*Carn.*	Llandudno	2·70	142
,,	Sherborne St. John	1·79	84	*Angl.*	Llanerchymedd	3·21	135
Herts.	Royston, Therfield Rec.	2·22	99	*I. Man.*	Douglas, Boro' Cem.	4·99	206
Bucks.	Slough, Upton	2·67	130	*Wigtown*	Pt. William, Monrieth	4·35	185
Oxford	Oxford, Radcliffe	1·08	48	*Dumf.*	Dumfries, Crichton R.I.	3·63	143
N'hant.	Wellingboro', Swanspool	1·34	64	,,	Eskdalemuir Obsy.	4·92	156
Essex	Shoeburyness	2·47	140	*Roxb.*	Kelso, Floors	4·28	203
Suffolk	Campsea Ashe, High Ho.	1·49	79	*Peebs.*	Stobo Castle	2·94	126
,,	Lowestoft Sec. School	0·97	87	*Berwick*	Marchmont House	2·89	125
,,	Bury St. Ed., Westley H.	3·26	155	*E. Loth.*	North Berwick Res.	3·04	183
Norfolk	Sandringham Ho. Gdns.	2·02	93	*Midl'n*	Edinburgh, Blackf'd. H.	2·97	149
Wilts.	Bishops Cannings	1·89	78	*Lanark*	Hamilton W.W., T'nhill	2·78	126
Dorset	Creech Grange	2·13	93	*Ayr*	Colmonell, Knockdolian	3·25	128
,,	Beaminster, East St.	2·45	108	,,	Glen Afton, Ayr San.	3·14	105
Devon	Teignmouth, Den Gdns.	2·68	140	*Bute*	Rothesay, Ardencraig	4·51	147
,,	Cullompton	2·65	125	*Argyll*	Loch Sunart, G'dale	5·73	178
,,	Barnstaple, N. Dev. Ath.	2·45	109	,,	Poltalloch	4·36	143
,,	Okehampton, Uplands	3·63	131	,,	Inveraray Castle	5·78	146
Cornwall	Bude School House	3·14	156	,,	Islay, Eallabus	3·88	148
,,	Penzance, Morrab Gdns.	3·44	155	,,	Tiree	3·69	145
,,	St. Austell, Trevarna	5·13	197	*Kinross*	Loch Leven Sluice	3·82	174
,,	Scilly, Tresco Abbey	4·14	239	*Fife*	Leuchars Airfield	2·55	153
Glos.	Cirencester	1·97	82	*Perth*	Loch Dhu	6·13	147
Salop	Church Stretton	1·53	60	,,	Crieff, Strathearn Hyd.	5·71	216
,,	Cheswardine Hall	1·23	50	,,	Blair Castle Gardens	3·49	176
Staffs.	Leek, Wall Grange P.S.	1·26	48	*Angus*	Montrose, Sunnyside	2·67	161
Worcs.	Malvern, Free Library	1·87	81	*Aberd.*	Balmoral Castle Gdns.	2·00	118
Warwick	Birmingham, Edgbaston	1·57	68	,,	Aberdeen Observatory	1·11	65
Leics.	Thornton Reservoir	1·30	60	,,	Fyvie Castle	1·75	83
Lincs.	Boston, Skirbeck	3·12	171	*Moray*	Gordon Castle	3·22	158
,,	Skegness, Marine Gdns.	2·30	128	*Nairn*	Nairn, Achareidh	3·06	173
Notts.	Mansfield, Carr Bank	1·77	78	*Inv's*	Loch Ness, Foyers	3·81	172
Ches.	Bidston Observatory	2·29	104	,,	Glenquoich	5·46	111
Lancs.	Manchester, Whit. Park	1·89	72	,,	Ft. William, Teviot	6·14	173
,,	Stonyhurst College	2·53	82	,,	Skye, Duntuilm	3·71	143
,,	Blackpool	2·85	131	*R. & C.*	Ullapool	2·96	130
Yorks.	Wakefield, Clarence Pk.	2·93	136	,,	Applecross Gardens	3·34	117
,,	Hull, Pearson Park	1·97	96	,,	Achnashellach	3·72	99
,,	Felixkirk, Mt. St. John	2·16	99	,,	Stornoway Airfield	2·68	122
,,	York Museum	3·32	160	*Suth.*	Lairg.	3·13	150
,,	Scarborough	2·22	121	,,	Loch More, Achfary	4·11	111
,,	Middlesbrough	2·37	125	*Caith.*	Wick Airfield	2·54	141
,,	Baldersdale, Hury Res.	3·96	168	*Shet.*	Lerwick Observatory	2·41	135
Norl'd.	Newcastle, Leazes Pk.	2·61	124	*Ferm.*	Crom Castle	3·75	138
,,	Bellingham, High Green	3·76	163	*Armagh*	Armagh Observatory	3·74	148
,,	Lilburn Tower Gdns.	2·15	105	*Down*	Seaforde	4·48	162
Camb.	Geltsdale	3·62	134	*Antrim*	Aldergrove Airfield	3·52	146
,,	Keswick, High Hill	3·15	108	,,	Ballymena, Harryville	4·17	143
,,	Ravenglass, The Grove	2·41	92	*Lon.*	Garvagh, Moneydig	5·63	222
Mon.	Abergavenny, Larchfield	1·89	77	,,	Londonderry, Creggan	4·16	148
Glam.	Ystalyfera, Wern Ho.	3·44	91	*Tyrone*	Omagh, Edenfel	4·56	162

CLIMATOLOGICAL TABLE FOR THE BRITISH COMMONWEALTH, FEBRUARY, 1947

STATIONS	PRESSURE		TEMPERATURES							RELATIVE HUMIDITY	MEAN CLOUD AMOUNT	PRECIPITATION			BRIGHT SUNSHINE	
	Mean of Day M.S.L.	Diff. from normal	Absolute		Mean Values							Total	Diff. from normal	Days	Daily mean	Per-cent of poss-ible
			Max.	Min.	Max.	Min.	½ Max. and Min.	Diff. from normal	Wet bulb							
	mb.	mb.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	%	0–10	in.	in.		hrs.	%
London, Kew Observatory	1007·9	−7·1	40	15	32·9	27·1	30·0	−10·7	28·3	82	8·7	1·19	−0·35	11	0·6	6
Gibraltar	1011·3	−8·7	71	42	62·4	52·0	57·2	−1·4	53·2	87	7·5	9·29	—	19	—	—
Malta	1009·2	−6·9	75	44	62·3	52·4	57·3	+2·0	54·8	73	5·6	0·33	—	4	6·9	63
St. Helena	1013·1	−2·8	78	59	70·9	61·9	66·4	+1·2	62·1	97	9·2	4·10	+1·42	19	—	—
Freetown, Sierra Leone.....	1010·1	+0·8	89	71	85·9	76·6	81·3	+0·6	75·1	80	5·2	0·10	−0·20	1	8·4	71
Lagos, Nigeria	1009·9	+0·2	96	67	92·3	73·6	82·9	+0·4	78·3	82	8·2	0·32	—	4	7·1	60
Kaduna, Nigeria	1008·3	—	98	60	95·1	65·8	80·5	+2·8	65·4	40	3·6	0·03	+0·01	1	9·6	81
Zomba, Nyasaland																
Salisbury, Rhodesia																
Cape Town	1013·6	+0·2	103	51	83·0	63·1	73·1	+2·8	62·9	68	1·8	0·07	−0·51	3	—	—
Germiston, South Africa	1011·7	—	87	55	80·1	59·4	69·7	—	60·1	64	3·5	3·89	—	13	8·9	69
Mauritius	1008·9	−1·9	90	71	86·5	74·3	80·4	+1·1	74·8	79	5·2	4·12	−3·39	16	9·2	72
Calcutta, Alipore Obsy.	1013·0	−0·5	90	52	85·2	60·8	73·0	+1·8	60·0	76	2·0	0·54	−0·45	3	9·2	81
Bombay	1011·1	−1·6	93	62	85·3	68·9	77·1	+1·4	67·4	78	1·1	0·00	−0·03	0	10·3	90
Madras	1012·2	−0·7	88	65	84·9	70·5	77·7	0·0	71·9	87	4·6	0·00	−0·30	0	9·1	78
Colombo, Ceylon	1010·6	−0·2	92	65	87·4	71·9	79·7	−0·7	71·8	87	3·9	1·66	−0·28	2	9·1	77
Singapore	1009·0	−1·2	89	71	85·9	73·0	79·5	−0·7	76·0	85	—	14·93	+8·31	18	—	—
Hongkong	1019·4	+0·8	74	43	62·4	52·1	57·3	−1·8	53·4	79	—	0·51	−1·32	5	4·6	40
Sydney, N.S.W.	1016·6	+2·7	94	61	77·2	67·1	72·1	+0·8	67·7	79	8·1	5·84	+1·64	15	4·9	36
Melbourne	1014·6	+0·1	98	46	83·6	61·4	72·5	+4·9	63·2	59	6·1	1·39	−0·32	7	7·1	53
Adelaide	1013·4	−0·9	105	54	88·5	65·8	77·1	+3·1	64·9	46	5·1	0·77	+0·05	5	8·6	57
Perth, W. Australia	1010·0	−3·0	100	55	86·8	64·5	75·7	+1·6	64·7	49	3·4	0·10	−0·35	2	10·6	80
Coolgardie	1010·8	−1·6	106	57	90·0	65·4	77·7	+1·5	62·1	49	4·0	0·18	−0·67	5	—	—
Brisbane	1014·4	+1·9	86	65	80·6	68·5	74·5	−2·0	69·8	68	7·7	9·77	+3·43	22	4·6	35
Hobart, Tasmania	1016·3	+3·1	88	46	74·4	54·1	64·3	+2·0	56·0	61	5·9	1·24	−0·24	7	8·9	65
Wellington, N.Z.	1018·2	+2·4	82	42	67·7	53·4	60·5	−0·7	56·5	75	7·2	5·75	+2·61	7	7·6	55
Suva, Fiji	1007·3	−0·5	89	70	85·3	73·9	79·6	−0·7	75·8	84	6·6	14·70	+3·98	18	7·0	55
Apia, Samoa	1007·4	−1·0	91	73	87·3	75·5	81·4	+2·4	78·4	82	7·6	10·36	−4·93	14	6·2	49
Kingston, Jamaica	1014·0	−1·3	88	65	85·4	70·1	77·7	+1·2	70·4	74	3·7	2·94	+2·34	8	8·0	69
Grenada, W. Indies	—	—	86	70	84·6	74·8	79·7	+2·6	74·4	77	7·0	0·18	−2·60	6	—	—
Toronto	1009·9	−8·1	43	3	28·9	16·3	22·6	+1·5	18·6	—	9·7	1·00	−1·38	15	2·4	23
Winnipeg	1022·8	+1·0	30	−29	8·4	−9·1	−0·3	−0·4	−5·1	—	6·6	1·24	+0·50	14	3·5	35
St. John, N.B.	1001·7	−12·2	47	4	32·2	18·6	25·4	+5·5	21·2	—	6·6	5·09	+1·19	14	3·6	35
Victoria, B.C.	1019·3	+2·7	59	20	49·7	33·5	41·6	+1·1	36·4	93	5·4	4·56	+1·30	8	4·0	39

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